Development of a low-pressure helium compression control strategy for CMTF

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Fermilab Cryomodule Test Facility

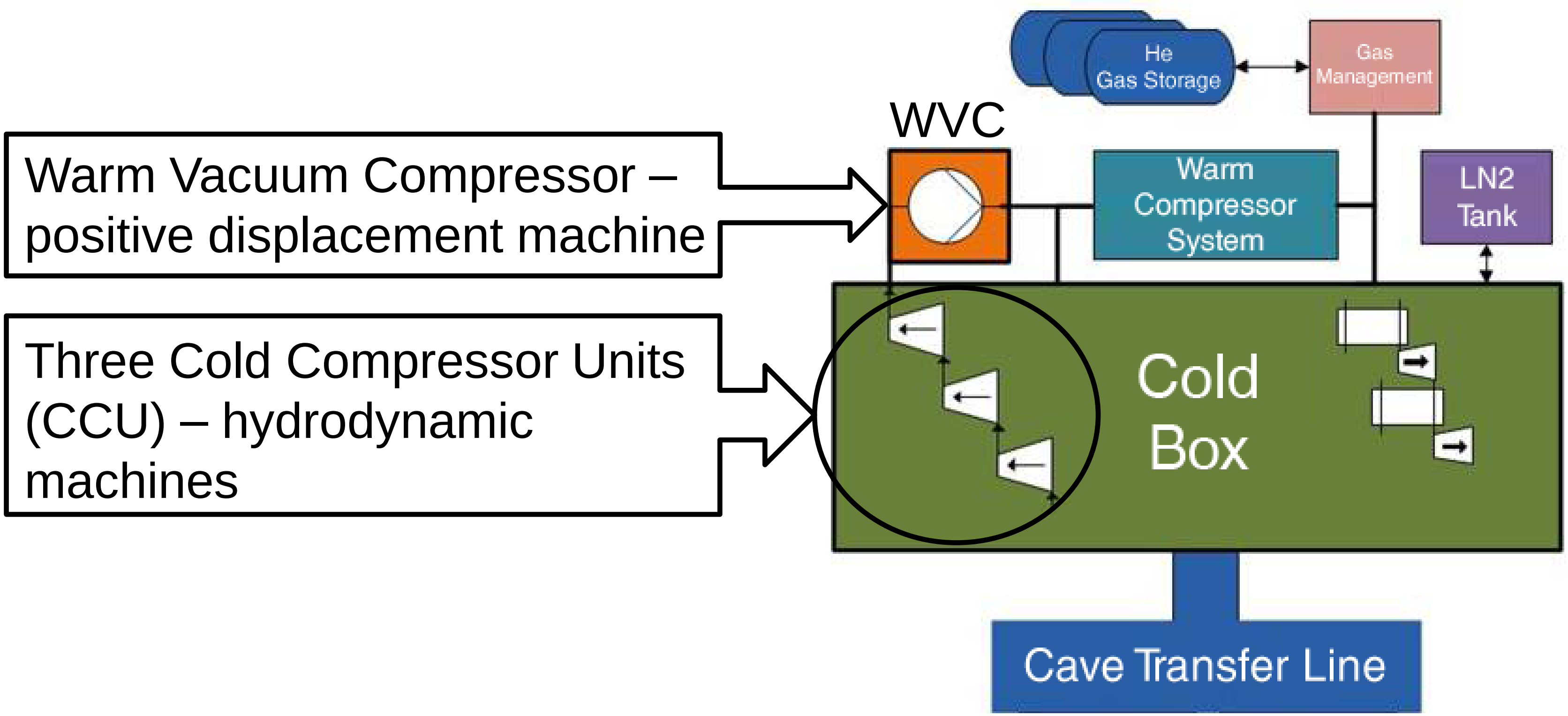
Fermilab Cryomodule Test Facility (CMTF) provides a test bed to measure the performance of cryomodules and SRF cavities for future accelerators (Project X, ILC, Muon Collider).

CMTF Refrigerator

- Must be capable to operate efficiently over a wide range of heat loads.
- Will be more energy efficient than any superfluid helium cryogenic system currently in operation in Fermilab.
- It is being designed as a one-size-fits-many cryogenic plant for the laboratory’s future research projects.

The Key is the Hybrid Cryogenic Cycle

- Use both warm and cold compression
- Efficient cryogenic capacity turndown is accomplished by adjusting a cryogenic system helium mass flow rate to match the heat load generated by SRF components.



Cold & Warm Compressors

Why Cold Compressors?

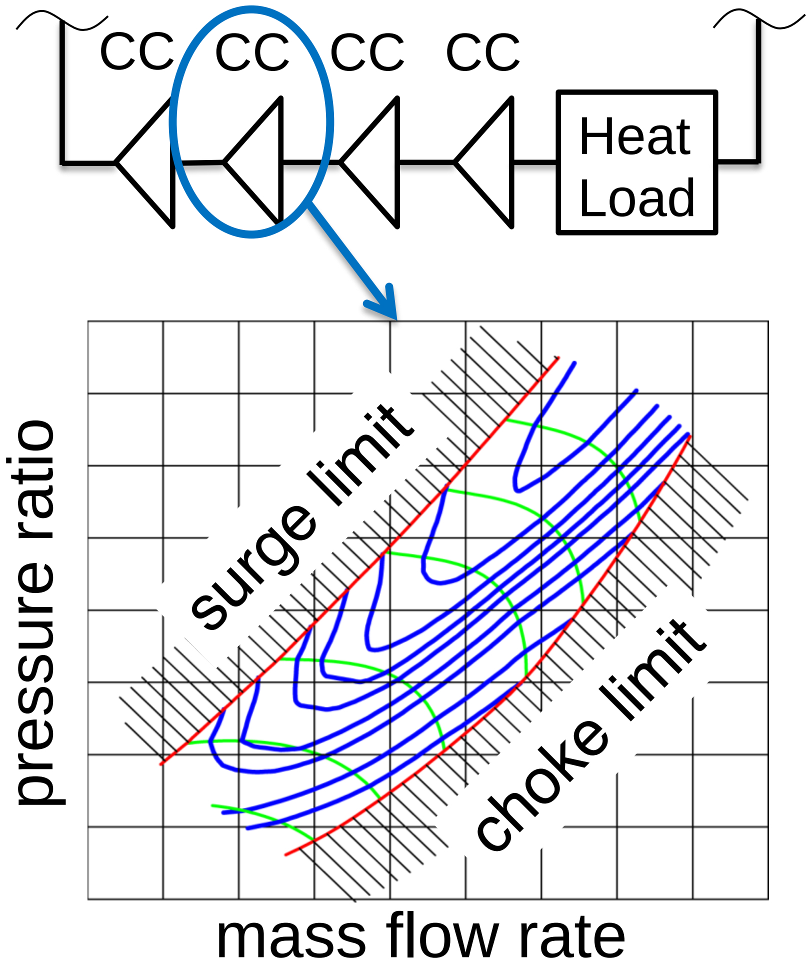
- Cold pumping allows recuperate cold before helium re-cooling → increasing overall efficiency
- The cold helium has a higher density → decreasing number of compression stages
- A compressor stage can have characteristics corresponding to optimal helium suction conditions → increasing adiabatic efficiency

Why Not Only Cold Compressors?

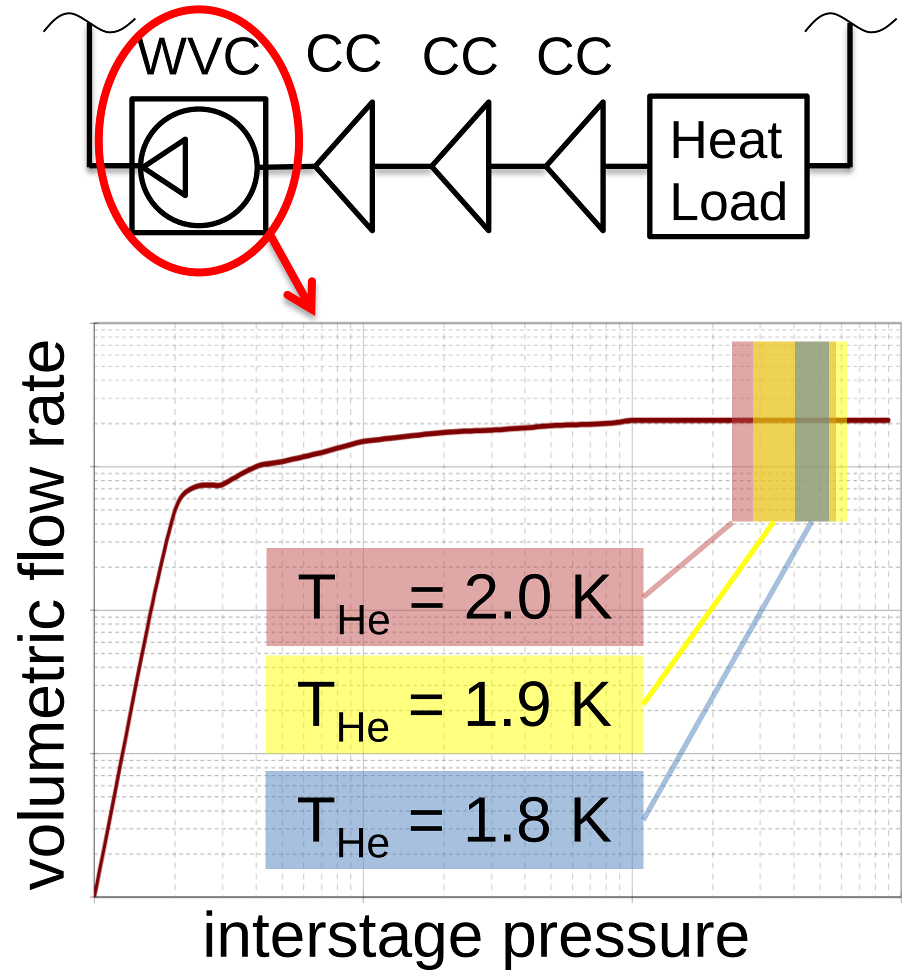
- Cold compressor set has the fixed pressure ratio → decreasing working mass flow range
- Limited turndown capability → decreasing efficiency

Cold & Hybrid Cycles Comparison

Multistage cold compressors – "cold" compression cycle

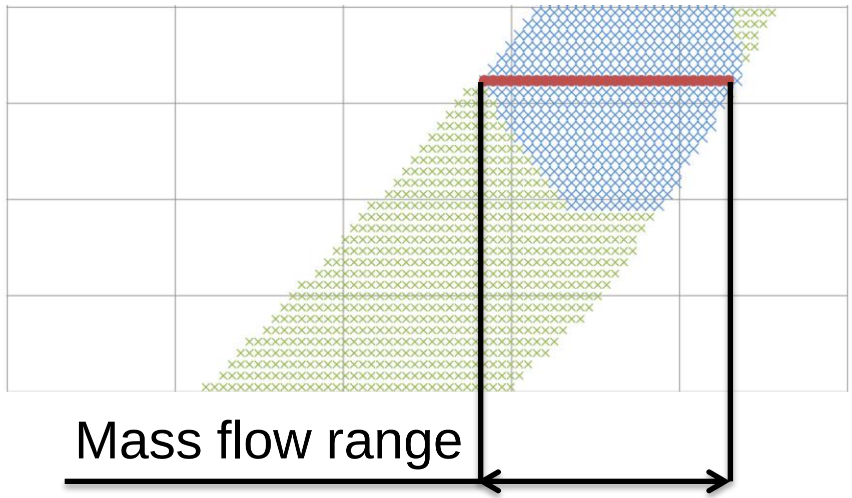


Cold compressors in series with warm compressor – "hybrid" cycle

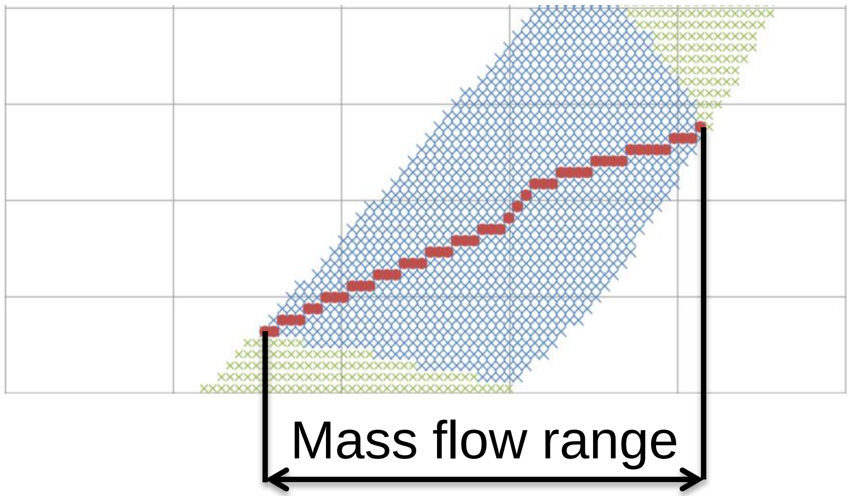


Mass Flow Rate Reduction Capability

“Cold” cycle:
pressure ratio ≈ const



“Hybrid” cycle:
pressure ratio is variable



$$Q = M \times H_{vap}$$

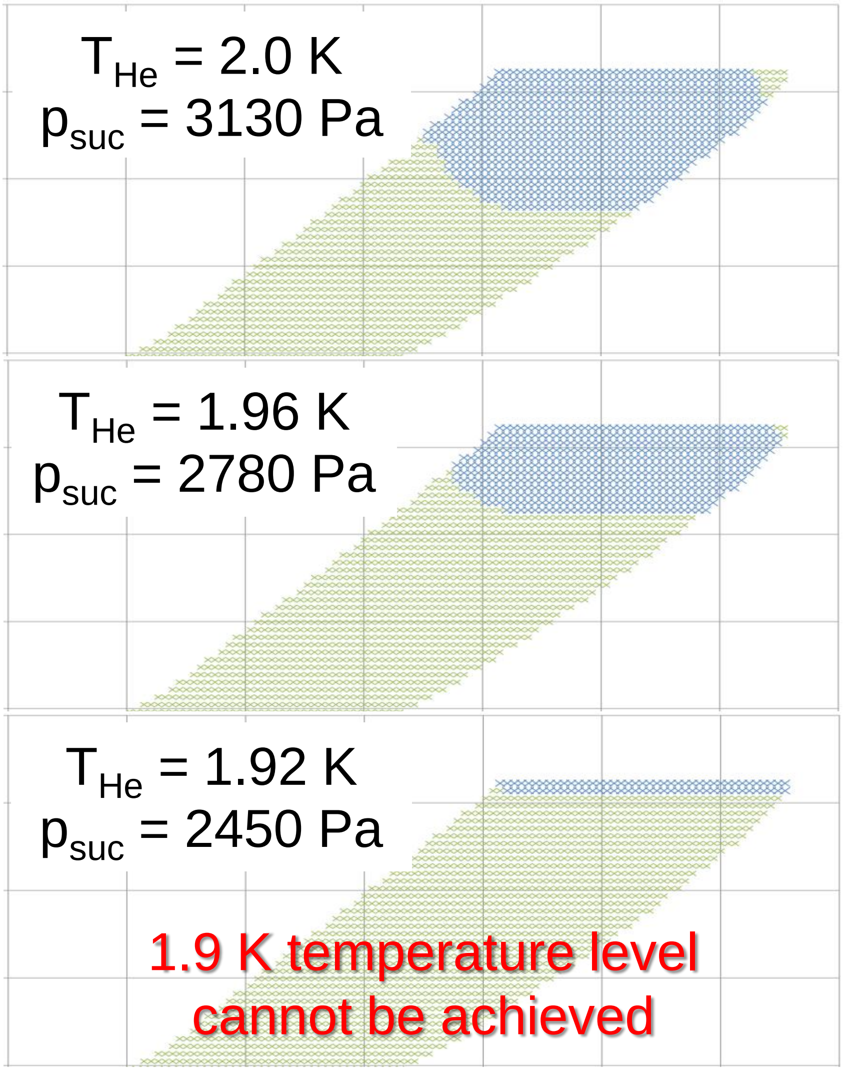
Q – Heat Load; M – Mass Flow Rate; H_{vap} – Heat of Vaporization

“Cold” cycle (T_{He} = 2.0 K):
M/M_{design} = 75% … 100%
Q/Q_{design} = 75% … 100%

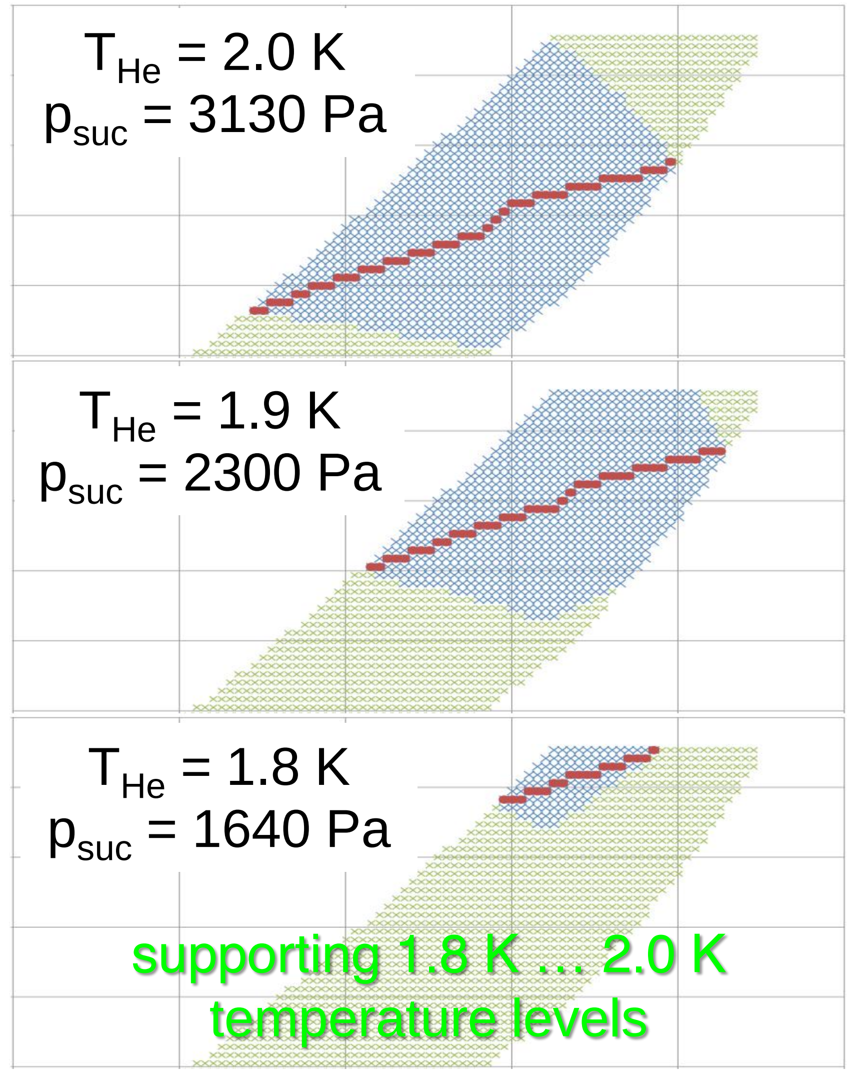
“Hybrid” cycle (T_{He} = 2.0 K):
M/M_{design} = 50% … 100%
Q/Q_{design} = 50% … 100%

Temperature Level Adjusting Capability

“Cold” cycle:



“Hybrid” cycle:



Conclusions

"Cold" cycle

- Using only cold compressors
- Easier to operate
- Limited capability
  - Single temperature level
  - Limited heat load range
- Requires use of resistive heating for operation in off-design mode

"Hybrid" cycle

- High dynamic range
  - Various temperature levels
  - Various heat load
- High efficiency in off-design mode without resistive heating
- Using volumetric machine
- Complex control system

Goals & Perspectives

- ✓ Develop cold compressor units control system strategy.
- ✓ Develop common control system strategy including cold compressor units and warm vacuum pump.
- ✓ Optimize control system strategy.
- ✓ Compare characteristics of cold and hybrid cycles using models of compression process.
- ❑ Develop static and dynamic models of coldbox including cold compressors, warm vacuum pump, heat exchangers and another equipment.
- ❑ Write a technical note.